AMAZONIANA	V	4	517–528	Kiel, April 1976

From cooperation between Max Planck Institute for Limnology, Department of Tropical Ecology, Plön, Germany, and Instituto Nacional de Pesquisas da Amazônia, Manaus–Amazonas, Brazil

Da cooperação entre Max-Planck-Institut für Limnologie, Abteilung Tropenökologie, Plön, Alemanha, e Instituto Nacional de Pesquisas da Amazônia, Manaus–Amazonas, Brasil

Primary Production of Phytoplankton in the Three Types of Amazonian Waters

IV. On the Primary Productivity of Phytoplankton in a Bay of the Lower Rio Negro (Amazonas, Brazil)

by

Gottfried W. Schmidt

1. Introduction

According to the generally accepted classification, a large part of the aquatic environment of the Amazon is placed in the category of black water on the basis of physico-chemical characteristics (SIOLI 1950, 1965, 1968 and others). For many reasons, conditions in black water are typically such that they are unfavourable for submerged plants and therefore also for phytoplankton, for example the very low pH, the extremely low and often imbalanced nutrient composition,and insufficient light in terms of both total transmission and spectral composition. These properties of Amazonian black waters have been well documented and substantiated for several water bodies (SIOLI 1950, 1955, 1968, GESSNER 1960, KLINGE & OHLE 1965, GEISLER 1967, 1969, MARLIER 1965, 1967, UNGEMACH 1967, WILLIAMS 1968, BRINKMANN & SANTOS 1970a, 1970b, SANTOS, SANTOS & BRINKMANN 1971, ANONYMOUS 1972, SCHMIDT 1972, and others).

There is little information on how far the unfavourable conditions in black water, especially in the Amazonas region, affect the phytoplankton. It seems, however, that the diversity of the phytoplanktonic forms when considering the total numbers of taxa in individual samples is far greater than could possibly have been predicted before (SCHMIDT & UHERKOVICH 1973, UHERKOVICH 1974). The absolute numbers of individuals are, however, characteristically very low (comp. SCHMIDT 1970).

Production measurements carried out by HAMMER (1965) in the Rio Negro and MARLIER (1965) in the Lago Rio Preto da Eva, an "estuarine" lake of the same river, helped to characterise more precisely the quantitative phytoplankton development in

Amazonian black water. Both authors, however, used the oxygen method which is possibly rather inaccurate under the prevailing experimental conditions, because oxygen demand in black water is considerable due to the high levels of organic (but non-planktonic) material *. The number of production determinations made by both the above mentioned authors was also so low as to make further generalisations difficult from their data.

This paper presents the results of an investigation which ran for a full year, and in which the sensitive C^{14} method was used. A combination of these data with those of HAMMER and MARLIER should give a more comprehensive idea of the primary production of Amazonian black water.

2. The sampling site

The investigations were carried out in the Ponta Negra Bay which is on the left bank of the Rio Negro about 15 km above the city of Manaus, Federal State of Amazonas (SCHMIDT 1973a). The sampling station was 200-300 m from the bank in a water depth of 8-10 m. The almost complete absence of current in this part of the river led to stratification of the water body which, in certain weather conditions, was even observed fairly early in the morning (see Table 1).

Table 1: Rio Negro, Ponta Negra bay
Temperatures in °C

Date	1.11. 1967	7.12. 1967	17.1. 1968	14.2. 1968	20.3. 1968	15.5. 1968	6.6. 1968	17.7. 1968	21.8. 1968	18.9. 1968	17.10. 1968	20.11. 1968	17.12. 1968
hour	8.30	8.30	8.30	8.30	9.00	8.30	9.00	9.30	8.30	8.00	8.30	9.00	9.00
depth, m													
0	30.4	31.6	28.9	28.8	29.0	27.7	27.5	28.1	29.1	29.0	29.2	29.7	29.8
0.5	-	-	-	-	28.9	27.4	27.5	27.9	29.2	29.0	29.2	29.5	29.8
1	30.2	31.0	28.9	28.8*	28.9	27.4	27.2	27.9	29.1	28.9	29.1	29.3	29.7
1.5	-	-	-	28.7	28.8	27.3	27.1	27.8	29.1	28.8	29.0	29.2	29.7
2	30.0	30.8	28.9	-	28.8	27.3	27.0	27.8	29.1	28.8	29.1	29.2	29.7
3	30.0	30.8	28.9	28.7	28.8	27.3	27.0	27.7	29.1	28.8	29.0	29.2	29.7
4	30.0	30.8	28.9	28.6									
5	30.0	30.8	28.9										
7	29.8	30.7	28.9										

*0.75 m

GEISLER (1969), working on a small tributary of the lower Rio Negro, reported that such temperature stratification in the inundated shore forests of Amazonian black water rivers (igapó) is accompanied by considerable oxygen deficits in the deeper water layers. Table 2 shows that this is also the case in similar areas of the Rio Negro itself. These results were obtained from the igapó forest on the shore almost opposite in the Ponta Negra i.e. from the right bank of the river. The shore of the bay where the actual sampling station was situated was always a sandy beach, except during the period of maximum water level.

---

*(GESSNER 1960, HAMMER 1965, GEISLER 1967, BRINKMANN & SANTOS 1970).

Table 2: Stratification of the water body in the inundated forest region (Igapó) of lower Rio Negro opposite the Ponta Negra Bay on August 7th, 1969.
Hour: 12.00
Secchi transparency: 1.5 m
Air temperature: 28.8 °C.

Depth, m	temperature, °C	Oxygen saturation, %
0	31.7	77.3
0.5	29.8	62.0
1	29.1	59.2
2	28.7	46.7
3	28.5	37.9
4	28.4	19.3
4.2 (bottom)	28.4	17.8

3. Sampling period and intervals

Production was determined at approximately monthly intervals between 1.11.1967 and 17.12.1968, thereby covering a full year with its corresponding vegetation growth period. No determination was made in April 1968 because of bad weather and damage to the equipment.

4. Methods

Production was determined in situ using the C^{14} method of STEEMAN NIELSEN (1952). Exposure was started in the morning, usually at 10 am, and lasted 24 hours. Dark bottles covered with aluminium foil were also placed at the minimum and maximum depths of each series. The production values given in the text are net values unless otherwise stated.

The amount of assimilatable carbon in the water was calculated in the usual manner from the values for free carbon dioxide and alkalinity, obtained by titration.

The depth of light penetration (transparency) was measured with a white Secchi disc.

Chlorophyll A was determined by extraction with ethanol.

The calibration curve was prepared in the same way using a pure chlorophyll preparation.

All methods, particularly those relating to production, were fully described and discussed in the previous publication in this series (SCHMIDT 1973b), so are not repeated here.

Many thanks are due to the Administração do Porto de Manaus, who willingly provided the water level figures for the Rio Negro.

5. Results

Tables 1 and 3-6 give the values for temperature, pH, alkalinity, electrical conductivity and free carbon dioxide at all depths on each sampling date. The free carbon dioxide concentrations showed the most variation over the year, the other parameters being fairly constant. As already mentioned, the water was sometimes thermally stratified as early as 10 am, when the exposures were started.

Table 3: Rio Negro, Ponta Negra bay
pH

Date	1.11. 1967	7.12. 1967	17.1. 1968	14.2. 1968	20.3. 1968	15.5. 1968	6.6. 1968	17.7. 1968	21.8. 1968	18.9. 1968	17.10. 1968	20.11. 1968	17.12. 1968
hour	8.30	8.30	8.30	8.30	9.00	8.30	9.00	9.30	8.30	8.00	8.30	9.00	9.00
depth, m													
0	5.3	5.2	5.4	5.0	5.0	4.8	4.9	4.9	4.9	5.1	5.1	5.0	5.2
0.5	-	-	-	-	5.0	4.8	4.9	4.9	4.9	5.2	5.1	5.0	5.2
1	5.3	5.2	5.4	5.0*	5.0	4.8	4.9	4.9	4.9	5.2	5.1	5.0	5.2
1.2	-	-	-	5.0	5.0	4.8	4.9	4.9	4.9	5.1	5.1	5.0	5.2
2	5.3	5.2	5.4	-	5.0	4.8	5.0	4.9	5.0	5.1	5.1	5.0	5.2
3	5.3	5.2	5.4	5.0	5.0	4.8	5.0	4.9	5.0	5.1	5.1	5.0	5.3
4	5.3	5.2	5.4	5.0									
5	5.3	5.2	5.4										
7	5.3	5.2	5.4										

*0.75 m

Table 4: Rio Negro, Ponta Negra bay
Electric conductivity in micromho/cm (uS$_{20}$/cm)

Date	1.11. 1967	7.12. 1967	17.1. 1968	14.2. 1968	20.3. 1968	15.5. 1968	6.6. 1968	17.7. 1968	21.8. 1968	18.9. 1968	17.10. 1968	20.11. 1968	17.12. 1968
hour	8.30	8.30	8.30	8.30	9.00	8.30	9.00	9.30	8.30	8.00	8.30	9.00	9.00
depth, m													
0	9.4	8.9	7.2	8.4	7.7	9.5	8.4	11.2	7.7	7.9	7.9	6.8	8.2
0.5	-	-	-	-	7.8	9.0	8.6	8.2	7.7	8.2	7.2	6.4	7.7
1	8.8	7.9	7.0	7.9*	7.9	8.8	8.6	8.2	7.7	8.2	7.5	6.7	7.7
1.5	-	-	-	7.9	7.8	8.8	8.7	8.2	7.7	8.2	7.5	6.7	7.7
2	8.6	8.0	7.0	-	7.9	8.8	8.7	8.0	7.6	8.1	7.4	6.7	7.7
3	8.6	7.9	7.0	7.9	7.9	8.8	8.7	8.0	7.6	8.1	7.5	6.6	7.7
4	8.6	7.9	7.0	7.9									
5	8.5	7.8	7.0										
7	7.8	7.6	6.8										

*0.75 m

Fig. 1 shows the vertical pattern of net primary productivity of the phytoplankton on each sampling day. The important features are as follows:

(a) The absolute values for primary productivity are, except in November and December 1967, extremely low. The production densities (production per unit volume) in the optimal depth zone varied between 0,181 and 0,0122 gC/m^3/d, therefore showing considerable fluctuation within the year of sampling.

(b) The general shape of the curves is similar, i.e. the maximum production density was always directly under the water surface (depth of surface exposure: about 5 cm), and values decreased sharply in the underlying water layers.

(c) Although the maximum production density was clearly higher in the first two months of sampling than for the rest of the time, the depth of the trophogenic zone was surprisingly constant at 2 m.

(d) The Secchi transparency was low throughout the year, varying between 1 and 1,5 m.

Table 5: Rio Negro, Ponta Negra bay
Alkalinity (Säurebindungsvermögen, SBV) in mval/l (meq./l)

Date	1.11. 1967	7.12. 1967	17.1. 1968	14.2. 1968	20.3. 1968	15.5. 1968	6.6. 1968	17.7. 1968	21.8. 1968	18.9. 1968	17.10. 1968	20.11. 1968	17.12. 1968
hour	8.30	8.30	8.30	8.30	9.00	8.30	9.00	9.30	8.30	8.00	8.30	9.00	9.00
depth, m													
0	0.13	0.08	0.08	0.08	0.08	0.02	0.03	0.02	0.02	0.03	0.03	0.02	0.03
0.5	-	-	-	-	0.08	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.03
1	0.13	0.10	0.07	0.08*	0.08	0.03	0.03	0.02	0.02	0.03	0.03	0.02	0.03
1.5	-	-	-	0.08	0.08	0.03	0.03	0.01	0.02	0.03	0.03	0.02	0.03
2	0.13	0.10	0.05	-	0.08	0.03	0.03	0.01	0.02	0.03	0.03	0.02	0.03
3	0.13	0.07	0.05	0.08	0.08	0.08	0.03	0.01	0.02	0.03	0.03	0.02	0.03
4	0.10	0.08	0.05	0.08									
5	0.10	0.08	0.05										
7	0.10	0.08	0.05										

*0.75 m

Table 6: Rio Negro, Ponta Negra bay
Free carbon dioxide in mg/l

Date	1.11. 1967	7.12. 1967	17.1. 1968	14.2. 1968	20.3. 1968	15.5. 1968	6.6. 1968	17.7. 1968	21.8. 1968	18.9. 1968	17.10. 1968	20.11. 1968	17.12. 1968
hour	8.30	8.30	8.30	8.30	9.00	8.30	9.00	9.30	8.30	8.00	8.30	9.00	9.00
depth, m													
0	4.1	2.8	3.4	3.5	3.7	7.8	9.3	11.5	6.4	5.9	5.0	3.1	3.2
0.5	-	-	-	-	3.7	9.0	10.0	11.5	6.6	5.9	5.1	3.2	3.2
1	3.4	2.8	3.2	3.7*	4.1	10.2	10.0	11.8	6.6	6.0	5.1	3.2	3.2
1.5	-	-	-	3.9	3.7	10.0	10.0	12.0	6.7	6.1	5.0	3.4	3.2
2	3.4	3.9	3.0	-	3.9	9.7	10.0	11.8	6.6	6.1	5.3	3.4	3.3
3	3.1	3.9	3.4	4.2	3.8	9.6	9.7	11.9	6.5	6.1	5.3	3.6	3.2
4	2.8	4.3	2.9	4.1									
5	2.9	4.1	3.4										
7	2.0	4.1	3.3										

*0.75 m

Planctonic primary production was usually zero at a depth less than twice the depth of light penetration. This indicates that the light climate in the water body is unfavourable for phytoplankton as a result of selective light extinction caused by dissolved humic substances, as well as of the general turbidity expressed in the low Secchi transparency values.

In Fig. 2 the values for maximum production density and area production (production per unit area) are compared with the chlorophyll content per unit volume at the depth of maximum production density and chlorophyll content per square meter of the trophogenic zone, and with the water level of the river during the investigation period. Unfortunately, the chlorophyll concentrations are lacking for the first month.

The period of investigation started in November 1967 shortly after the water level of the Rio Negro had reached its annual minimum. As shown in Fig. 2, planktonic primary production at this time was highest for the year; production then decreased with increasing water depth. The December figures show that the chlorophyll content as well as possib-

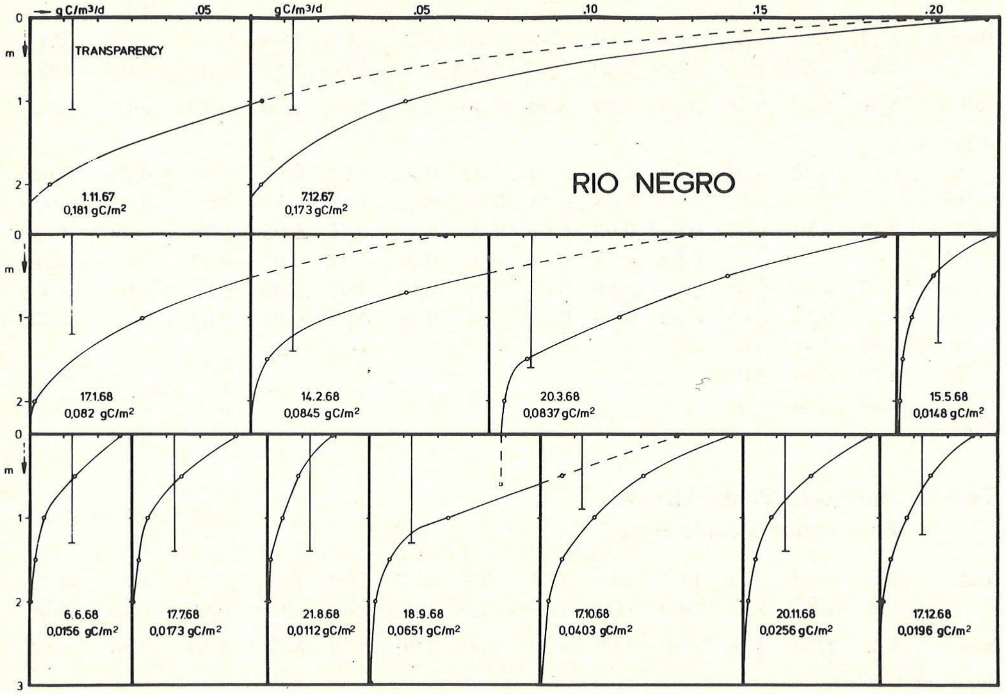

Fig. 1: Rio Negro, Ponta Negra bay.
Vertical pattern of net primary productivity of phytoplankton during the 24 hour exposure of the monthly investigations from November, 1967 to December, 1968.

ly the population density of the phytoplankton, reached a maximum at low water level. Primary production and chlorophyll content dropped continuously thereafter, finally reaching minimum levels at maximum water depth. When the water level decreased again, the values did not reach the maximum levels of the last months of 1967. Since the water level was considerably higher in November and December 1968 than in the same period of 1967 (Fig. 2), these two factors are probably related. This point is dealt with more fully in the discussion.

The dark fixation of C^{14} varied in samples exposed at the water surface between 0,0011 and 0,0088 g $C/m^3/d$ i.e. between 2,7 and 11,8 % of the net productivity at the same water layer (Fig. 3). The mean values were 0,0038 g $C/m^3/d$ and 5,6 % respectively. Fig. 3 also shows that dark fixation comprised a conspicuously higher percentage during the time of lowest net production density i.e. in the high water period, than at any other time.

Gross productivity was determined indirectly. According to the method recommended by STEEMAN NIELSEN & JENSEN (1957), a good approximation can be obtained by summing, for all depths of the trophic zone, 10 % of the value for maximum production density. Gross planktonic primary productivity for this series is then 0,030-0,434 g $C/m^3/d$

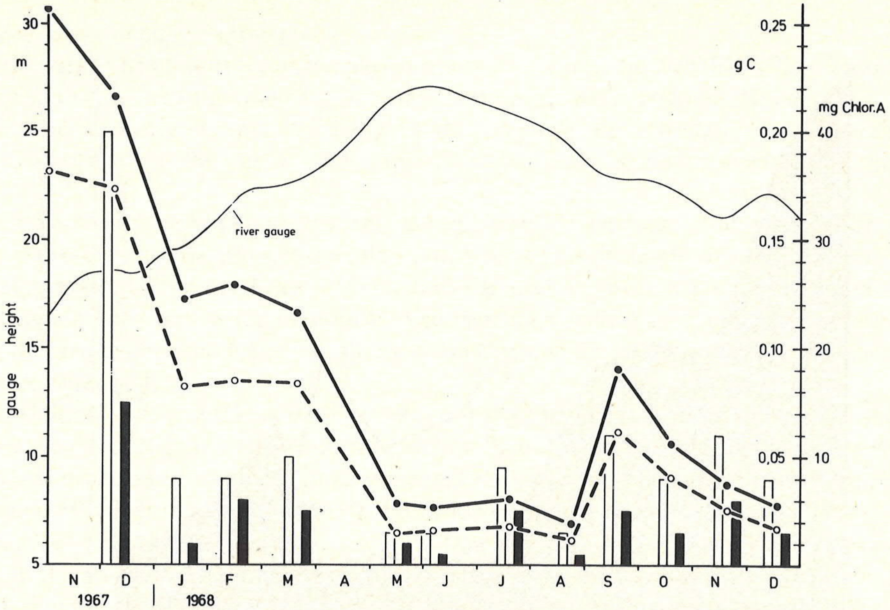

Fig. 2: Rio Negro, Ponta Negra bay.
Net primary productivity of phytoplankton per unit volume at optimum depth ($gC/m^3/d$, black points), and per unit area ($gC/m^2/d$, white circles, broken line) compared with the chlorophyll A content per unit volume at depth of maximum productivity (mg Chlor. A/m^3, black columns), with the chlorophyll A content per unit area of the trophogenic zone (mg Chlor. A/m^2, white columns), and with the height of river gauge during the investigation period.

i.e. on average about twice as much as net production.

The mean net area production for the year was 0,063 g $C/m^2/d$. The Rio Negro with its tropical climate has an uninterrupted vegetation growth period, so a figure for annual productivity can be obtained by multiplying this figure by 365, giving a value for this particular year of 230 kg C/ha.

6. Discussion

As shown in Fig. 2, the curve of planktonic primary production declined markedly over the year without returning to its original level in the last months of 1968. Assuming that this is an actual trend, the reason for it must be established. In investigations of the primary productivity of phytoplankton in the várzea lake Lago do Castanho (also near Manaus) it was found that the daily fluctuations in production were relatively insignificant, so that results obtained from taking monthly samples should be representative for the season (SCHMIDT 1973b). Time did not permit a similar investigation in the lower Rio Negro; however, the climatic conditions at the two sites are comparable as they are not far apart. It is therefore assumed that the production levels established at monthly intervals on the lower Rio Negro are typical for the sampling site.

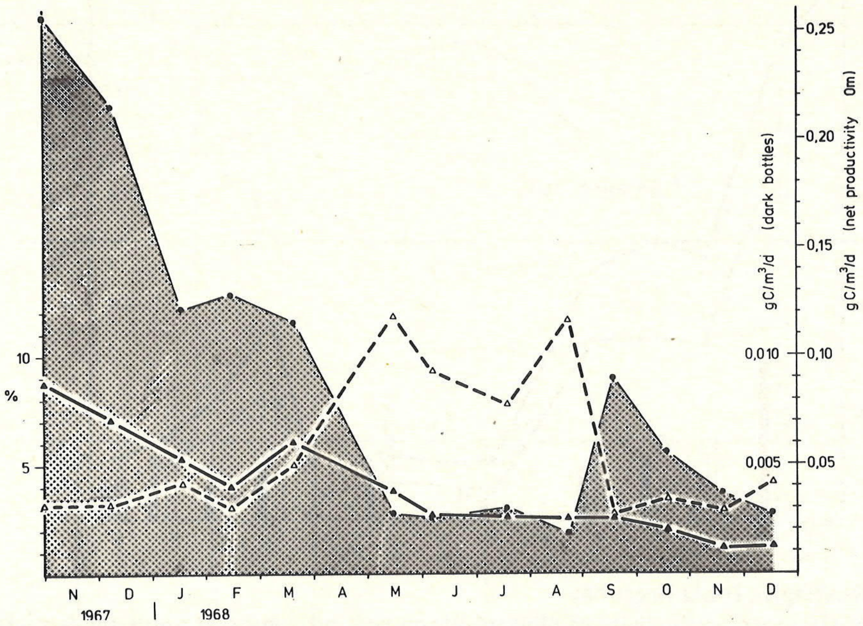

Fig. 3: Rio Negro, Ponta Negra bay.
Dark fixation of C^{14} during the exposures (black triangles), and the percentage of dark fixation in relation to net productivity at water surface (white triangles) compared with net productivity per unit volume at the same depth (black points, dark field).

Optical conditions are probably not responsible, since as shown by the Secchi transparency readings in Fig. 1, the degree of water turbidity was relatively constant throughout the sampling period. The Pt values of UNGEMACH (ANONYMOUS 1972) show that this is also true of the water colour.

In contrast, it seems that changes in water level (Fig. 2) affect the curve. The level of the river in November and December 1968 was 5 m higher than in the same period of 1967; this was because the river did not recede as usual in the latter half of 1968. This difference had far-reaching consequences for the whole ecosystem and for planktonic primary productivity (SCHMIDT 1973b) in the Lago do Castanho which is subjected to approximately the same water level fluctuations. Probably the main factors controlling planktonic primary production in the lower Rio Negro are likewise dependant on the water level changes and therefore on the precipitation. This applies especially to the nutrient supply. As BRAUN (1952) realised, the plant nutrients made available by remineralisation in the dry shore region during low water and which are washed out into the water body at the start of the rains, play a role which should not be neglected in view of the very low nutrient content of most Amazonian waters. He called this the "shore factor". The so-called "dilution factor", a result of heavy rainfall, counteracts this. Since in 1968 there was practically no low water period in Manaus and the rainfall was also heavy in the usually dry period, it is assumed, that there was no accumulation of remineralised plant nutrients, or that any such accumulation became rapidly diluted. Because of this, the production figures decreased instead of increasing as excepted in September.

Analysis of Rio Negro water samples in the years 1965-67 by UNGEMACH suggest that during the low water period there is a slight but detectable increase in the concentrations of some plant nutrients, especially nitrate and phosphorus (ANONYMOUS 1972). This was obviously not the case in 1968, but unfortunately no figures are available for this year.

The results of this study are probably not applicable to all Amazonian black water bodies. However, since the physico-chemical properties of black waters are comparable in most respects (see references in the introduction) the levels of primary productivity established here can be viewed as representative. Also significant with regard to broader application of the results obtained is the fact that the Rio Negro is the largest and most characteristic black water body.

HAMMER (1965) working in the weakly flowing part of the Rio Negro opposite the banks of the Ponta Negra obtained area production figures of 79 and 131 mg C/m²/d in two series; these values agree well with those presented in this paper. The same is true of primary production figures obtained by MARLIER (1965) from the Lago Rio Preto da Eva.
The results of both HAMMER and myself show that the production density was always maximum in the water layer directly beneath the surface, then decreased rapidly with increasing water depth; the data of MARLIER, however, show that the production maximum in some cases was found somewhat deeper.

The influence of low nutrient concentrations on productivity in black water was investigated in some fertilization experiments, and it was shown that production in Rio Negro water samples increased considerably with increasing nutrient concentration. These experiments indicate that the production capacity of the phytoplankton population present in the water body (comp. Fig. 2 and SCHMIDT 1970) can not nearly be fully utilised with such naturally low nutrient concentrations. The fertilization experiments will be reported in another paper (SCHMIDT in preparation).

In summary, the following general characteristics of primary productivity of the phytoplankton on the basis of the results presented here can be mentioned:

The absolute value for primary production (production density as well as area production) is very low. These two aspects of the productivity exhibit considerable seasonal fluctuations which seem to be primarily a result of the indirect consequences of water level fluctuations. The depth of the trophogenic zone remains fairly constant throughout the year. With respect to both nutrients and light, conditions for planktonic primary production are extremely unfavourable, the nutrient content of the water being the main limiting factor.

7. Summary

Planktonic primary production was measured at monthly intervals between 1.11.1967 and 17.12. 1968 in a bay of the lower Rio Negro, using the C^{14} method.

The net production per unit volume varied between 0,0191 and 0,2664 g $C/m^3/d$ and per surface area between 0,0112 and 0,181 g $C/m^2/d$. The chlorophyll A content varied in the optimal depth zone between 1 and 15 mg/m^3, and between 3 and 40 mg/m^2 per unit area of the trophogenic zone.

The depth of the trophogenic zone was relatively constant throughout the year at 2 m.

The gross production was determined as being approximately 0,03 to 0,43 g $C/m^2/d$, and therefore on average about twice as great as the corresponding net production.

The dark fixation of carbon dioxide also fluctuated considerably, the values varying between 0,0011 and 0,0088 g C/m^3/d. This corresponded to 2,7 and 11,8 % respectively (mean 5,6 %) of the net production.

Since the sampling area has a tropical climate there is no interruption in the vegetation growth period for the phytoplankton in the course of a year, so the annual productivity could be calculated by multiplying the mean daily value (0,063 g C/m^3/d) by 365. With this conversion factor the value obtained is relatively high (230 kg C/ha/year), in view of the unfavourable nutrient and light conditions.

The extremely poor nutrient supply and the unfavourable light conditions in the black water of the lower Rio Negro must be considered as responsible for the characteristically low primary productivity here. These factors have been mentioned by various authors.

The fluctuations in the level of primary productivity and the characteristic inverse relationship between it and water level is a result of seasonality. There are several indications that the nutrient supply is better during the low water period, although much work can still be done in this field. These points are dealt with in detail in the discussion.

The nutrient factor is, as far as can be seen from these results, the most important factor limiting primary production of phytoplankton in the black water of the lower Rio Negro.

8. Resumo

Na época entre 1.11.67 e 17.12.68 foi analisada a produção primária do fitoplancton em uma baía do Rio Negro inferior através do método C-14 em espaços mensais.

A produção liqüida por unidade de volume situou-se entre 0,0191 e 0,2664 g C/m^3/d e por unidade de superfície entre 0,0112 e 0,181 g C/m^2/d. O teor de clorofila A variou na zona de profundidade ótima entre 1 e 15 mg/m^3. As concentrações de clorofila A variaram entre 3 e 40 mg/m^3 por unidade de superfície da zona trofogênica.

Contràriamente, a espessura da zona trofogênica manteve-se relativamente constante ao redor de 2 m durante todo o ano.

A produção bruta foi avaliada a grosso modo com válores entre 0,03 e 0,43 g C/m^2/d. Com isso atingia em média valôres cerca de 100 % superiores aos da produção liqüida correspondente.

Variações significantes também foram observadas na fixação escura do C-14. Ela flutuava entre 0,0011 e 0,0088 g C/m^3/d. Isto correspondeu a 2,7 - 11,8 % resp. em média a 5,6 % da produção liqüida.

Como não ocorre interrupção do período vegetativo durante o ano para o fitoplancton na área de investigação devido ao clima puramente tropical, pode ser calculada a ordem de grandeza da produtividade anual através da multiplicação do valor diário médio (0,063 g C/m^3/d) com 365. Através dêste alto fator de cálculo atingiu-se o resultado relativamente alto de 230 kg C/ha/a para o ano atual, face às condições de nutrientes e de luz desfavoráveis.

Como causas para as cifras de produção primária muito baixas do Rio Negro inferior devem ser mencionadas a oferta de nutrientes extremamente baixa e as condições de luz desfavoráveis na água preta, que são conhecidas porém neste intermédio através de numerosas publicações de diversos autores.

As variações da produtividade primária do fitoplâncton encontradas, que podem ser caracterizadas por uma proporcionalidade inversa entre nivel d'água e produtividade, podem ser relacionadas com as épocas do ano. Apesar de, neste contexto, ainda ficarem abertas importantes investigações, há diversos indícios de que o suprimento de nutrientes é um pouco melhor na época da água baixa. Na discussão esta questão é tratada mais profundamente.

O fator nutriente é o fator mais limitante da produção primária do fitoplâncton na água preta do Rio Negro inferior, pelo menos no que as investigações permitem reconhecer.

(Tradução de Reimar Schaden, M.Sc.)

9. References

ANONYMOUS (1972): Die Ionenfracht des Rio Negro, Staat Amazonas, Brasilien, nach Untersuchungen von Dr. Harald Ungemach. - Amazoniana, Kiel, 3: 175 - 185.

ANONYMOUS (1972): Regenwasseranalysen aus Zentralamazonien, ausgeführt in Manaus, Brasilien, von Dr. Harald Ungemach. - Amazoniana, Kiel, 3: 186-198.

BRAUN, R. (1952): Limnologische Untersuchungen an einigen Seen im Amazonasgebiet. - Schweiz.Z. Hydrol. 14: 1-128.

BRINKMANN, W.L.F. & SANTOS, A. dos (1970): Natural Waters in Amazonia II. The Chemical Oxygen Demand (COD). - Symposium Proceedings on Environment in Amazonia, Part I; Manaus April 4, 1970, p. 57 - 66.

BRINKMANN, W.L.F. & SANTOS, A. dos (1972): Time depency of hydrogen-ion concentration and electric conductivity measurements in river water samples of Central Amazonia. - Acta Amazônica, Manaus 1: 57 - 62.

GEISLER, R. (1967): Zur Limnochemie des Igarapé Preto. - Amazoniana, Kiel 1: 117 - 123.

GEISLER, R. (1969): Untersuchungen über den Sauerstoffgehalt, den biochemischen Sauerstoffbedarf und den Sauerstoffverbrauch von Fischen in einem tropischen Schwarzwasser (Rio Negro, Amazonien, Brasilien). - Arch. Hydrobiol. 66 : 307 - 325.

GESSNER, F. (1960): Limnologische Untersuchungen am Zusammenfluß des Rio Negro und des Amazonas (Solimões). - Int.Rev.ges.Hydrobiol. 45: 55 - 79.

HAMMER, L. (1965): Photosynthese und Primärproduktion im Rio Negro. - Int.Rev.ges.Hydrobiol. 50: 335 - 339.

KLINGE, H. & OHLE, W. (1965): Chemical properties of rivers in the Amazonian area in relation to soil conditions. - Verh. Internat. Verein Limnol. 15: 1067 - 1076.

MARLIER, G. (1965): Etude sur les lacs de l'Amazonie Centrale. - Cadernos da Amazonia, Manaus 5: 1 - 51.

SANTOS, U. de M., SANTOS, A. dos & BRINKMANN, W.L.F. (1971): A composição quimica do Rio Prêto da Eva-Amazonia. Estudo preliminar. - Ciencia e cultura, São Paulo 23: 643 - 646.

SCHMIDT, G.W. (1970): Numbers of bacteria and algae and their interrelations in some Amazonian waters. - Amazoniana, Kiel, 2: 393 - 400.

SCHMIDT, G.W. (1972): Chemical properties of some waters in the tropical rain-forest region of Central-Amazonia along the new road Manaus-Caracarai. - Amazoniana, Kiel 3: 199 - 207.

SCHMIDT, G.W. (1973a): Primary production of phytoplankton in the three types of Amazonian waters. I. Introduction. - Amazoniana, Kiel 4: 135 - 138

SCHMIDT, G.W. (1973b): Primary production of phytoplankton in the three types of Amazonian waters. III. Primary productivity of phytoplankton in a tropical flood-plain lake of Central Amazonia (Lago do Castanho, Amazonas, Brazil). - Amazoniana, Kiel 4: 379 - 404.

SCHMIDT, G.W. (in prep.): Primary production of phytoplankton in the three types of Amazonian waters. VI. Results of some fertilization experiments with natural phytoplankton samples of Amazonian waters.

SCHMIDT, G.W. & UHERKOVICH, G. (1973): Zur Artenfülle des Phytoplanktons in Amazonien. - Amazoniana, Kiel, 4: 243 - 252.

SIOLI, H. (1950): Das Wasser im Amazonasgebiet. - Forsch.Fortschr. 26: 274 - 280.

SIOLI, H. (1955): Beiträge zur regionalen Limnologie des Amazonasgebietes. III. Über einige Gewässer des oberen Rio Negro-Gebietes. - Arch.Hydrobiol. 50: 1 - 32.

SIOLI, H. (1965): Bemerkungen zur Typologie amazonischer Flüsse. - Amazoniana 1: 74 - 83.

SIOLI, H. (1968): Hydrochemistry and Geology in the Brazilian Amazon Region. - Amazoniana 1: 267 - 277.

STEEMAN NIELSEN, E. (1952): The use of radioactive carbon (C-14) for measuring of organic production in the sea. - J. Cons. Int. Explor. Mer 18: 117 - 140.

STEEMAN NIELSEN, E. & JENSEN, A. (1957): Primary organic production. The autotrophic matter in the oceans. - Galathea Report 1: 49 - 136.

UHERKOVICH, G. (in press): Phytoplanktontaxa in den beiden amazonischen Flüssen Rio Negro und Rio Tapajóz. - Amazoniana.

UNGEMACH, H. (1967): Sôbre o balança metabôlico de iones inorgânicos da área do sistema do Rio Negro. - Atas do Simposio sôbre a Biota Amazonica, 3: 221 - 226.

WILLIAMS, P.M. (1968): Organic and Inorganic Constituents of the Amazon River. - Nature 218: 937 - 938.

Author's address:

Dr. G.W. Schmidt
Landesanstalt für Fischerei NW
D-5942 Kirchhundem - Albaum
Fed. Rep. Germany

Accepted for publication in February 1974